DP-302466

APPARATUS AND METHOD FOR RETENTION OF NON-THERMAL PLASMA REACTOR

CROSS REFERENCE TO RELATED APPLICATIONS

The application is related to U.S. Patent No. 6,159,430 the contents of which are incorporated herein by reference thereto.

TECHNICAL FIELD

This application relates to a non-thermal plasma reactor for reduction of nitrogen oxides (hereinafter NO_x). More particularly, this application relates to methods of retaining a plasma-generating substrate in a non-thermal plasma reactor.

BACKGROUND

The removal of NO_x from the exhaust gases of internal combustion engines is required for cleaner operating vehicles. Improvements in fuel efficiency are achieved by operating at conditions with an excess of air than required for stoichiometric combustion (i.e., lean burn or rich conditions). Such "lean burn" conditions are commonly achieved in diesel engines and four cycle engines. However when lean-burn conditions are employed, common pollution reduction devices (e.g., three-way catalysts) are inefficient in the reduction of nitrogen oxides.

One approach to reduce nitrogen oxide pollutants in exhaust gases of engines operating under lean-burn conditions has been to incorporate a non-thermal plasma reactor in the exhaust lines along in addition to a catalyst converter formulated for the NO_x reduction. Such reactors treat the exhaust gases using a non-thermal plasma field. The plasma converts NO to NO_2, the NO_2 must then be subsequently reduced by a selective catalyst. For example, a non-thermal plasma reactor is described in U.S. patent No. 6,139,694, the contents of which are incorporated by reference herein.

Non-thermal plasma reactors include a non-thermal plasma-generating substrate ("substrate") disposed within a housing. The substrate includes a plurality of dielectric plates each being spaced from one another to form a plurality of exhaust gas flow channels. Preferably, the dielectric plates are non-conductive materials such as quartz, glass, alumina, mullite, and oxide free ceramics (e.g., silicon nitrite, boron nitrite, aluminum nitrite). A voltage supply is connected to a pair of electrodes on each dielectric plate for providing a voltage between the dielectric plates in order to generate the plasma field in the flow channel between the plates. The exhaust gas flows through the flow channel, exposing the gas to the plasma field. The plasma field converts NO into nitrogen dioxide or NO_2.

The dielectric plates are prone to crushing from forces applied to the surface of the plates parallel to the flow passage due to the thin cross section of the plates and due to the fact that they are only supported at two sides of the passage. Thus, the forces necessary to restrain the substrate in the housing may damage the unsupported surface areas and may bend or deform the outer plates into the flow passage. The substrate must be isolated from the housing to prevent high voltage arcing from a buss line termination on the substrate to the housing. Moreover, the substrate is subject to heating and cooling cycles, which places an additional strain on the substrate. These factors and others create obstacles with respect to retaining the substrate in the reactor.

SUMMARY

A non-thermal plasma reactor including a plasma-generating substrate, a housing, a high voltage feed through device, and a retention material is provided. The plasma-generating substrate has one or more flow passages for an exhaust gas. The plasma-generating substrate includes a weak area and a strong area. The housing has an inlet opening and an outlet opening. The voltage is supplied to the plasma-generating substrate for generating a plasma field through the high voltage feed through device. The retention material retains the plasma-generating substrate in the housing such that the flow passages are in fluid communication with the inlet opening and the outlet opening. The retention material is configured to provide a higher retention

force to the at least one strong area, and a lower retention force to the at least one weak area to seal the exhaust gas bypass.

A unitary exhaust system component comprising a non-thermal plasma reactor, a particulate filter, and a catalytic converter in a single housing is provided. The non-thermal plasma reactor oxidizes nitrogen oxides to nitrogen dioxide in an exhaust stream and includes an inlet opening and an outlet opening. The plasma-generating substrate has one or more exhaust passages in fluid communication with the inlet opening and the outlet opening. A voltage is supplied to the plasma-generating substrate for generating a plasma field. The particulate filter captures particulate matter from the exhaust stream upstream of the substrate. The catalytic converter for removes the nitrogen dioxide, hydrocarbon and carbon monoxide from the exhaust stream downstream of the substrate.

A first or stuffing method of retaining a non-thermal plasma substrate is provided. The method includes providing a housing, providing a plasma-generating substrate, wrapping the plasma-generating substrate with a retention material, and stuffing the plasma-generating substrate wrapped with the retention material in the housing. The housing has a first open end and a second open end. The non-thermal plasma-generating substrate has one or more flow paths for an exhaust gas and a weak area and a strong area. The non-thermal plasma-generating substrate is stuffed into the housing through the first open end or the second open end such that the flow paths are in fluid communication with the open ends. Thus, the retention material provides a higher retention force to the strong area and a lower retention force to the weak area.

A second or clamping method of retaining a non-thermal plasma substrate is provided. The method includes providing two half shells defining a housing, providing a plasma-generating substrate, wrapping the plasma-generating substrate with a retention material, and securing the first half shell to the second half shell to retain the plasma-generating substrate in the housing. The plasma-generating substrate has one or more flow paths for an exhaust gas and includes at least one weak area and at least one strong area. The plasma-generating substrate is secured in the housing such that the retention material

provides a higher retention force to the at least one strong area and a lower retention force to the at least one weak area.

The above-described and other features and advantages of the present application will be appreciated and understood by those skilled in the art from the following detailed description, drawings, and appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a partial exploded view of a non-thermal plasma reactor retained in a housing by a first retention method;

Figure 2 is an exploded view of an exemplary embodiment of a non-thermal plasma reactor retained in a housing by a second retention method;

Figure 3 is an end view of the non-thermal plasma reactor of Figure 2, taken along lines 3-3;

Figure 4 is a perspective view of a substrate of a non-thermal plasma reactor;

Figure 5 is a cross sectional view of an alternative embodiment of the present invention;

Figure 6 is a sectional view along lines 6-6 of Figure 5;

Figure 7 is a cross sectional view of an alternative embodiment of the present invention;

Figure 8 is a cross sectional view of another alternative embodiment of the present invention;

Figure 9 is a cross sectional view of yet another alternative embodiment of the present invention;

Figure 10 is a plan view of an exemplary embodiment of an exhaust system including a non-thermal plasma reactor; and

Figure 11 is a plan view of an alternate exemplary embodiment of an exhaust system including a non-thermal plasma reactor.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to Figure 1, an exemplary embodiment of a non-thermal plasma reactor 10 is illustrated. Non-thermal plasma reactor 10 (reactor) includes a housing 12. As illustrated in Figure 1, housing 12 is an

elongated cylinder with open ends. It also contemplated for housing 12 to have alternate configurations including, but not limited to elongated rectangular, ovals, trapezoids and the like. An end cap 14 is secured at each of the open ends of housing 12 defining an inlet opening 15 and an outlet opening 17. Reactor 10 includes a retention material 16 and a substrate 18. Substrate 18, described in detail below, is a non-thermal plasma-generating substrate that generates a plasma field in the substrate. Exposing exhaust gas to the plasma field in substrate 18 converts NO into nitrogen dioxide NO_2.

Housing 12 as illustrated in Figure 1 has a one-piece construction. In this embodiment, substrate 18 and housing 12 have a circular cross section. Preferably, housing 12 is made of material capable of withstanding the high temperature (e.g., in excess of 500 degrees Celsius) and high corrosive working environment of reactor 10. For example, housing 12 is made of metal, such as stainless steel. Retention material 16 is adapted to retain substrate 18 in housing 12 and to seal the gap between the substrate and the housing. Preferably, substrate 18 is wrapped with retention material 16 and inserted into housing 12 by appropriate means, such as being fed by a guide (not shown). Reactor 10 is completed by connecting, such as by welding, ends 14 to housing 12. Accordingly, Figure 1 illustrates a first or stuffing retention method for retaining substrate 18 in housing 12.

Housing 12 illustrated in Figures 2 and 3 has a two-piece or clamp shell construction including a pair of shells 13. In this embodiment, substrate 18 and housing 12 have a rectangular cross section. Preferably, substrate 18 is wrapped with retention material 16 and is placed between shells 13. Shells 13 are clamped to one another securing substrate 18 therein. Accordingly, Figures 2 and 3 illustrates a second or clamping retention method for retaining substrate 18 in housing 12. As illustrated in Figure 2, reactor 10 includes a voltage port 20 and a ground 24. Voltage port 20 supplies high voltage to substrate 18.

It should be recognized that housing 12, retention material 16 and substrate 18 are described above by way of example only as having one-piece construction and circular cross-sections in the stuffing method and two-piece construction and rectangular cross-sections in the clamping method,

respectively. However, any combination of multiple piece construction and corresponding cross sections used for either the stuffing or the clamping method are considered within the scope of the present application.

A gap 21 is defined between substrate 18 and housing 12. Gap 21, typically a minimum of about 19 mm, electrically isolates housing 12 from substrate 18 in order to prevent electrical arcing of the current of substrate 18 to housing 12. It should be recognized that gap 21 is described above by way of example as about 19mm, however the gap having any dimension sufficient to electrically isolate housing 12 from substrate 18 is within the scope of the invention. Retention material 16 fills gap 21 between housing 12 and substrate 18, and forms an interference fit with the housing to hold the substrate in the appropriate location. Preferably, retention material 16 is a compressible fiber material, thus the compression of the retention material forming the interference fit with housing 12 provides the retention forces necessary to retain substrate 18 in the housing. Retention material 16 is made of a high temperature resistive ceramic fiber material, preferably comprising alumina.

Retention material 16 is adapted to absorb the thermal expansion and compression of substrate 18, which is in the range of about $7x10^{-6}$ mm per degree Celsius. For example, retention material 16 is 1100HT supplied by 3M Company, which is capable of withstanding the temperature environment within reactor 10 and is capable of retaining substrate 18 throughout the expansion and contraction of the substrate.

Retention material 16, such as the 1100HT described above, includes a plurality of fibers bound together with a binder, often hydrocarbon based binders. The binder is used to improve material handling (i.e., prevent loss of fibers during handling) of retention material 16. It is possible for the binder that to become conductive when heated during use. Thus during manufacture of reactor 10, the reactor is pre-heat to a high enough temperature to burn out the binder material prior to use. In the example described above where retention material 16 is 1100HT, reactor 10 is pre-heated to about 500 degrees C to burn off any binder from the retention material.

Referring now to Figure 4, substrate 18 configured for use with housing 12 is illustrated. Substrate 18 includes a plurality of ceramic plates 34.

Each ceramic plate 34 is held in a spaced relation to other ceramic plates by a plurality of spacers 38. Thus, plates 34 and spacers 38 define a plurality of rectangular flow paths 36 there between. In a first embodiment, substrate 18 is provided as a single piece assembly having plates 34 and spacers 38 adhered together. In alternate embodiments, substrate 18 is a multi-piece assembly. Applying high voltage electricity to plates 34 generates the non-thermal plasma field necessary to convert NO into nitrogen dioxide NO_2.

Substrate 18 is positioned within housing 12 such that flow paths 36 are aligned with and in fluid communication with inlet opening 15 and outlet opening 17 of the housing. Thus in use, exhaust gas is directed into housing 12 through inlet opening 15, into flow paths 36 where the exhaust gas is exposed to the non-thermal plasma field. The exhaust gas exists flow paths 36 of substrate 18 and is directed out of housing 12 through outlet opening 17.

Flow paths 36 produce structurally weak zones or areas 40 of plates 34 of substrate 18. Areas 40 are capable of withstanding low loading forces, and are therefore susceptible to crush during stuffing or clamping of the substrate. Substrate 18 also includes medium strength load bearing areas 42 and high strength load bearing areas 44 in plates 34. Areas 42 and 44 are formed at the intersection of plates 34 and spacers 38, and are capable of withstanding higher loading forces than areas 40. Thus, the varying strength of areas 40, 42 and 44 affect how substrate 18 is retained in housing 12.

Referring now to Figures 5 and 6, substrate 18 is illustrated retained in housing 12 by retention material 16 with respect to the location of areas 40, 42 and 44 in the housing. Substrate 18 has a large weight relative to its medium strength areas 42 and high strength areas 44. However, prior reactors 10 wrapped retention material 16 about substrate 18 without consideration for where the retention forces supplied by the retention material act. In use, reactor 10 is subjected to forces, such as road impact forces and vibrational forces. Accordingly and in order to protect substrate 18, these forces are dampened by retention material 16 such that the substrate is held in place in housing 12 without damaging or crushing the substrate.

It has been determined that retention material 16 should provide higher retention forces to substrate 18 in its medium strength areas 42 and high

strength areas 44, but lower retention forces to the substrate in its low strength areas 40. Accordingly, retention material 16 is applied in the manners described below for providing higher retention forces at medium strength areas 42 and high strength areas 44, but lower retention forces at low strength areas 40.

Referring now to Figures 7 through 9, exemplary embodiments of reactor 10 are provided. Figures 7 through 9, similar to Figure 6, are cross sections of reactor 10, but for purposes of clarity refrain from illustrating certain aspects of the reactor.

For example, retention material 16 is adapted to provide unequal retention forces depending on the strength of substrate 18 by using multiple layers of the retention material having varying densities. In the embodiment of Figure 7, reactor 10 has an equal gap 21 between housing 12 and substrate 18 around all sides of the substrate. Retention material 16 includes a first layer 46 and a second layer 48. Second layer 48 is wrapped about substrate 18 at medium strength areas 42 and high strength areas 44. First layer 46 is then wrapped about second layer 48 and low strength areas 40 of substrate 18. Accordingly, retention material 16 provides a single layer of support at low strength areas 40 and a double layer of support at medium strength areas 42 and high strength areas 44. Thus at the single layer of retention material 16, the retention material provides a lower retention force to substrate 18. However at the double layers of retention material 16, the retention material provides a higher retention force to substrate 18.

Alternatively, housing 12 is adapted to provide unequal retention forces depending on the strength of substrate 18 by using multiple gap distances between the substrate and housing 12. In the embodiment of Figure 8, retention material 16 has a single insulation layer. Reactor 10 has an unequal gap between housing 12 and substrate 18. More specifically, housing 12 has a first or narrower gap 52 at medium strength areas 42 and high strength areas 44 of substrate 18, and has a second or wider gap 54 at low strength areas 40. A single layer 56 of retention material 16 is wrapped about substrate 18. Accordingly, the retention forces applied to low strength areas 40 by layer 56 are less than the retention forces applied to medium strength areas 42 and high

strength areas 44 of the substrate due to the variance between first gap 52 and second gap 54.

Similarly, in the embodiment of Figure 9, reactor 10 has an unequal gap between housing 12 and substrate 18. Here, housing 12 has a first or narrower gap 52 at high strength areas 44 of substrate 18, and has a second or wider gap 54 at low strength areas 40 and medium strength areas 44. A single layer 56 of retention material 16 is wrapped about substrate 18. Accordingly, the retention forces applied to low strength areas 40 and medium strength areas 42 by layer 56 are less than the retention forces applied to high strength areas 44 of the substrate due to the variance between first gap 52 and second gap 54.

It should be recognized that substrate 18 has been described above as being retained in housing 12 by way of example as either by multiple layers of the retention material having varying densities or multiple gap distances between the substrate and the housing. It is intended that the combination of such multiple densities and multiple gap distances be within the scope of the invention.

Also illustrated in Figure 9, substrate 18 and/or housing 12 include a coating material 60. Coating material 60 is provided on the interior of housing 12 and the exterior of substrate 18. In a first embodiment, coating material 60 is a coating of high friction material on housing 12 and substrate 18 to increase the retention forces applied by retention material 16. In another embodiment, coating material 60 is a coating of electrical insulating material on housing 12 and substrate 18 to increase the electrical isolation between the substrate and the housing. In yet another embodiment, coating material 60 provides both electrical insulating properties and high friction properties to housing 12 and substrate 18.

Referring now to Figure 10, a unitary exhaust system component 70 is shown including reactor 10, a particular filter 72 and a NO_x catalytic converter 74. Thus, unitary exhaust system component 70 is an integral unit having reactor 10, particular filter 72 and converter 74 in a single housing 76. Thus, particulate filter 72 being in fluid communication with inlet opening 15 of reactor 10 is adapted to remove carbon particles from exhaust prior to the exhaust entering substrate 18 of reactor 10. Next, the exhaust passes through

reactor 10 and then through catalytic converter 74. Accordingly, unitary exhaust system component 70 effectively reduces the pollutants in the exhaust.

Referring now to Figure 11, an alternate embodiment of unitary exhaust system component 70 is illustrated. It has been found that the conversion of NOx to nitrogen dioxide lowers the temperature at which diesel particulates burn. In the embodiment of Figure 11, reactor 10 is upstream of particular filter 72 and NO_x catalytic converter 74. Here, reactor 10 exhausts nitrogen dioxide into particular filter 72. Due to the lower combustion temperatures in nitrogen dioxide, particulate in particular filter 72 self ignites at temperatures that occur during normal driving. Exhaust gas flows through inlet opening 15 of reactor 10, out of outlet opening 17 into particulate filter 72. Next, the exhaust passes through catalytic converter 74. Accordingly, unitary exhaust system component 70 effectively reduces the pollutants in the exhaust.

While the invention has been described with reference to one or more exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiments disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.